



## 2009 $F = ma$ Contest

25 QUESTIONS - 75 MINUTES

### INSTRUCTIONS

**DO NOT OPEN THIS TEST UNTIL YOU ARE TOLD TO BEGIN**

- Use  $g = 10 \text{ N/kg}$  throughout this contest.
- You may write in this booklet of questions. However, you will not receive any credit for anything written in this booklet.
- Your answer to each question must be marked on the optical mark answer sheet.
- Select the single answer that provides the best response to each question. Please be sure to use a No. 2 pencil and completely fill the box corresponding to your choice. If you change an answer, the previous mark must be completely erased.
- Correct answers will be awarded one point; incorrect answers will result in a deduction of  $\frac{1}{4}$  point. There is no penalty for leaving an answer blank.
- A hand-held calculator may be used. Its memory must be cleared of data and programs. You may use only the basic functions found on a simple scientific calculator. Calculators may not be shared. Cell phones may not be used during the exam or while the exam papers are present. You may not use any tables, books, or collections of formulas.
- This test contains 25 multiple choice questions. Your answer to each question must be marked on the optical mark answer sheet that accompanies the test. Only the boxes preceded by numbers 1 through 25 are to be used on the answer sheet.
- All questions are equally weighted, but are not necessarily the same level of difficulty.
- **In order to maintain exam security, do not communicate any information about the questions (or their answers or solutions) on this contest until after February 20, 2009.**
- The question booklet and answer sheet will be collected at the end of this exam. You may not use scratch paper.

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1. A 0.3 kg apple falls from rest through a height of 40 cm onto a flat surface. Upon impact, the apple comes to rest in 0.1 s, and  $4 \text{ cm}^2$  of the apple comes into contact with the surface during the impact. What is the average pressure exerted on the apple during the impact? Ignore air resistance.

- (A) 67,000 Pa
- (B) 21,000 Pa
- (C) 6,700 Pa
- (D) 210 Pa
- (E) 67 Pa

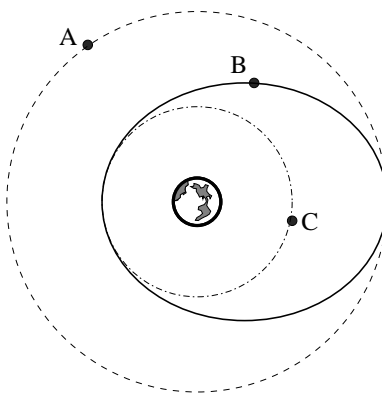
**The following information is used for questions 2 and 3.**

Three blocks of identical mass are placed on a frictionless table as shown. The center block is at rest, whereas the other two blocks are moving directly towards it at identical speeds  $v$ . The center block is initially closer to the left block than the right one. All motion takes place along a single horizontal line.



2. Suppose that all collisions are instantaneous and perfectly elastic. After a long time, which of the following is true?
- (A) The center block is moving to the left.
  - (B) The center block is moving to the right.
  - (C) The center block is at rest somewhere to the left of its initial position.
  - (D) The center block is at rest at its initial position.
  - (E) The center block is at rest somewhere to the right of its initial position.
3. Suppose, instead, that all collisions are instantaneous and perfectly inelastic. After a long time, which of the following is true?
- (A) The center block is moving to the left.
  - (B) The center block is moving to the right.
  - (C) The center block is at rest somewhere to the left of its initial position.
  - (D) The center block is at rest at its initial position.
  - (E) The center block is at rest somewhere to the right of its initial position.
4. A spaceman of mass 80 kg is sitting in a spacecraft near the surface of the Earth. The spacecraft is accelerating upward at five times the acceleration due to gravity. What is the force of the spaceman on the spacecraft?
- (A) 4800 N
  - (B) 4000 N
  - (C) 3200 N
  - (D) 800 N
  - (E) 400 N

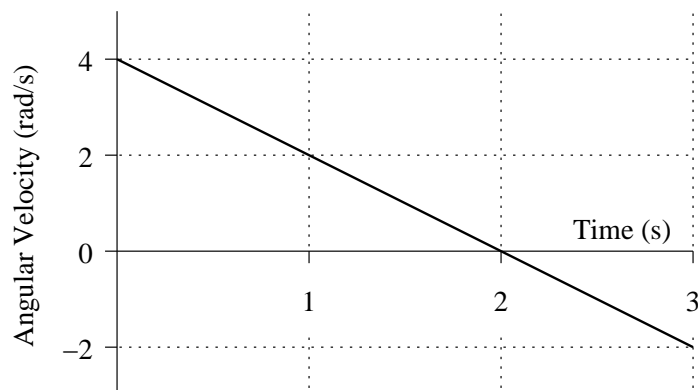
5. Three equal mass satellites  $A$ ,  $B$ , and  $C$  are in coplanar orbits around a planet as shown in the figure. The magnitudes of the angular momenta of the satellites as measured about the planet are  $L_A$ ,  $L_B$ , and  $L_C$ . Which of the following statements is correct?



- (A)  $L_A > L_B > L_C$   
 (B)  $L_C > L_B > L_A$   
 (C)  $L_B > L_C > L_A$   
 (D)  $L_B > L_A > L_C$   
 (E) The relationship between the magnitudes is different at various instants in time.
6. An object is thrown with a fixed initial speed  $v_0$  at various angles  $\alpha$  relative to the horizon. At some constant height  $h$  above the launch point the speed  $v$  of the object is measured as a function of the initial angle  $\alpha$ . Which of the following best describes the dependence of  $v$  on  $\alpha$ ? (Assume that the height  $h$  is achieved, and assume that there is no air resistance.)
- (A)  $v$  will increase monotonically with  $\alpha$ .  
 (B)  $v$  will increase to some critical value  $v_{\max}$  and then decrease.  
 (C)  $v$  will remain constant, independent of  $\alpha$ .  
 (D)  $v$  will decrease to some critical value  $v_{\min}$  and then increase.  
 (E) None of the above.
7. A bird is flying in a straight line initially at 10 m/s. It uniformly increases its speed to 15 m/s while covering a distance of 25 m. What is the magnitude of the acceleration of the bird?
- (A) 5.0 m/s<sup>2</sup>  
 (B) 2.5 m/s<sup>2</sup>  
 (C) 2.0 m/s<sup>2</sup>  
 (D) 0.5 m/s<sup>2</sup>  
 (E) 0.2 m/s<sup>2</sup>

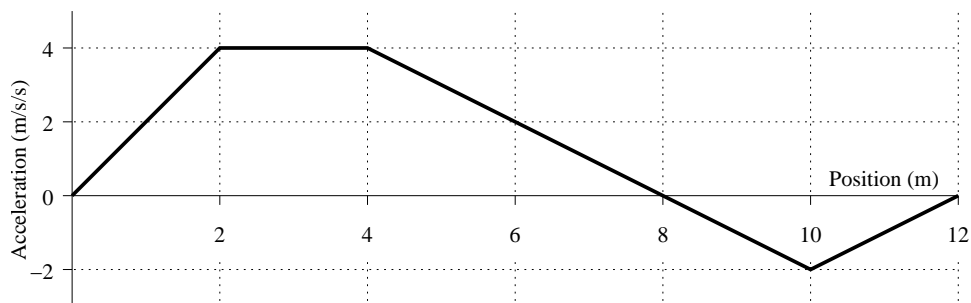
The following information is used for questions 8 and 9.

A flat disk rotates about an axis perpendicular to the plane of the disk and through the center of the disk with an angular velocity as shown in the graph below.



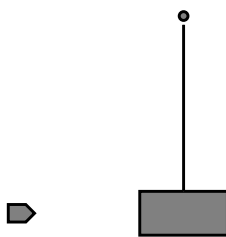
8. Determine the angular acceleration of the disk when  $t = 2.0$  s.
- (A)  $-12 \text{ rad/s}^2$ .
  - (B)  $-8 \text{ rad/s}^2$ .
  - (C)  $-4 \text{ rad/s}^2$ .
  - (D)  $-2 \text{ rad/s}^2$ .
  - (E)  $0 \text{ rad/s}^2$ .
9. Through what net angle does the disk turn during the 3 seconds?
- (A) 9 rad.
  - (B) 8 rad.
  - (C) 6 rad.
  - (D) 4 rad.
  - (E) 3 rad.
10. A person standing on the edge of a fire escape simultaneously launches two apples, one straight up with a speed of  $7 \text{ m/s}$  and the other straight down at the same speed. How far apart are the two apples 2 seconds after they were thrown, assuming that neither has hit the ground?
- (A) 14 m
  - (B) 20 m
  - (C) 28 m
  - (D) 34 m
  - (E) 56 m

11. A 2.25kg mass undergoes an acceleration as shown below. How much work is done on the mass?



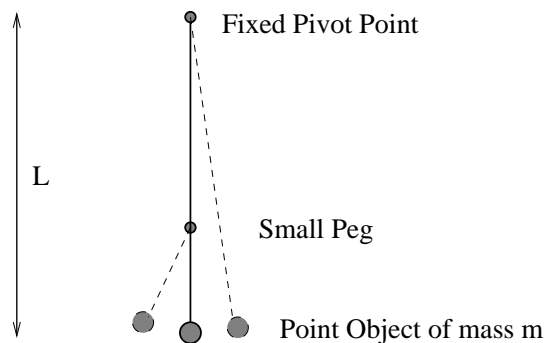
- (A) 36 J  
(B) 22 J  
(C) 5 J  
(D) -17 J  
(E) -36 J
12. Batman, who has a mass of  $M = 100$  kg, climbs to the roof of a 30 m building and then lowers one end of a massless rope to his sidekick Robin. Batman then pulls Robin, who has a mass of  $m = 75$  kg, up the roof of the building. Approximately how much total work has Batman done after Robin is on the roof?
- (A) 60 J  
(B)  $7 \times 10^3$  J  
(C)  $5 \times 10^4$  J  
(D) 600 J  
(E)  $3 \times 10^4$  J
13. Lucy (mass 33.1 kg), Henry (mass 63.7 kg), and Mary (mass 24.3 kg) sit on a lightweight seesaw at evenly spaced 2.74 m intervals (in the order in which they are listed; Henry is between Lucy and Mary) so that the seesaw balances. Who exerts the most torque (in terms of magnitude) on the seesaw? Ignore the mass of the seesaw.
- (A) Henry  
(B) Lucy  
(C) Mary  
(D) They all exert the same torque.  
(E) There is not enough information to answer the question.

14. A wooden block (mass  $M$ ) is hung from a peg by a massless rope. A speeding bullet (with mass  $m$  and initial speed  $v_0$ ) collides with the block at time  $t = 0$  and embeds in it. Let  $S$  be the system consisting of the block and bullet. Which quantities are conserved between  $t = -10$  s and  $t = +10$  s?



- (A) The total linear momentum of  $S$ .  
 (B) The horizontal component of the linear momentum of  $S$ .  
 (C) The mechanical energy of  $S$ .  
 (D) The angular momentum of  $S$  as measured about a perpendicular axis through the peg.  
 (E) None of the above are conserved.
15. A 22.0 kg suitcase is dragged in a straight line at a constant speed of 1.10 m/s across a level airport floor by a student on the way to the 40th IPhO in Merida, Mexico. The individual pulls with a  $1.00 \times 10^2$  N force along a handle with makes an upward angle of 30.0 degrees with respect to the horizontal. What is the coefficient of kinetic friction between the suitcase and the floor?
- (A)  $\mu_k = 0.013$   
 (B)  $\mu_k = 0.394$   
 (C)  $\mu_k = 0.509$   
 (D)  $\mu_k = 0.866$   
 (E)  $\mu_k = 1.055$
16. Two identical objects of mass  $m$  are placed at either end of a spring of spring constant  $k$  and the whole system is placed on a horizontal frictionless surface. At what angular frequency  $\omega$  does the system oscillate?
- (A)  $\sqrt{k/m}$   
 (B)  $\sqrt{2k/m}$   
 (C)  $\sqrt{k/2m}$   
 (D)  $2\sqrt{k/m}$   
 (E)  $\sqrt{k/m}/2$
17. You are given a standard kilogram mass and a tuning fork that is calibrated in Hz. You are also provided with a complete collection of laboratory equipment, but none of it is calibrated in SI units. You do not know the values of any fundamental constants. Which of the following quantities could you measure in SI units?
- (A) The acceleration due to gravity.  
 (B) The speed of light in a vacuum.  
 (C) The density of room temperature water.  
 (D) The spring constant of a given spring.  
 (E) The air pressure in the room.

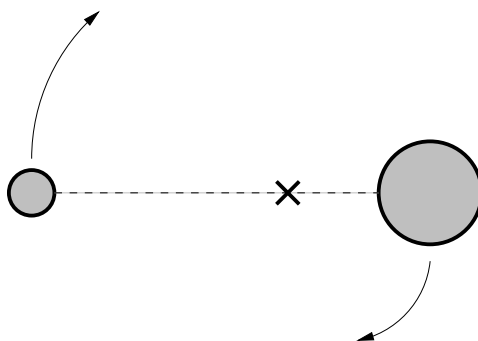
18. A simple pendulum of length  $L$  is constructed from a point object of mass  $m$  suspended by a massless string attached to a fixed pivot point. A small peg is placed a distance  $2L/3$  directly below the fixed pivot point so that the pendulum would swing as shown in the figure below. The mass is displaced 5 degrees from the vertical and released. How long does it take to return to its starting position?



- (A)  $\pi\sqrt{\frac{L}{g}}\left(1 + \sqrt{\frac{2}{3}}\right)$   
 (B)  $\pi\sqrt{\frac{L}{g}}\left(2 + \frac{2}{\sqrt{3}}\right)$   
 (C)  $\pi\sqrt{\frac{L}{g}}\left(1 + \frac{1}{3}\right)$   
 (D)  $\pi\sqrt{\frac{L}{g}}\left(1 + \sqrt{3}\right)$   
 (E)  $\pi\sqrt{\frac{L}{g}}\left(1 + \frac{1}{\sqrt{3}}\right)$
19. A certain football quarterback can throw a football a maximum range of 80 meters on level ground. What is the highest point reached by the football if thrown this maximum range? Ignore air friction.
- (A) 10 m  
 (B) 20 m  
 (C) 30 m  
 (D) 40 m  
 (E) 50 m
20. Consider a completely inelastic collision between two lumps of space goo. Lump 1 has mass  $m$  and originally moves directly north with a speed  $v_0$ . Lump 2 has mass  $3m$  and originally moves directly east with speed  $v_0/2$ . What is the final speed of the masses after the collision? Ignore gravity, and assume the two lumps stick together after the collision.
- (A)  $7/16 v_0$   
 (B)  $\sqrt{5}/8 v_0$   
 (C)  $\sqrt{13}/8 v_0$   
 (D)  $5/8 v_0$   
 (E)  $\sqrt{13/8} v_0$

The following information is used for questions 21 and 22.

Two stars orbit their common center of mass as shown in the diagram below. The masses of the two stars are  $3M$  and  $M$ . The distance between the stars is  $d$ .



21. What is the value of the gravitational potential energy of the two star system?

- (A)  $-\frac{GM^2}{d}$
- (B)  $\frac{3GM^2}{d}$
- (C)  $-\frac{GM^2}{d^2}$
- (D)  $-\frac{3GM^2}{d}$
- (E)  $-\frac{3GM^2}{d^2}$

22. Determine the period of orbit for the star of mass  $3M$ .

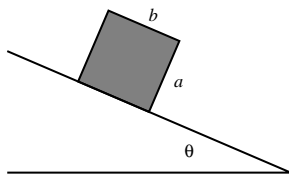
- (A)  $\pi\sqrt{\frac{d^3}{GM}}$
- (B)  $\frac{3\pi}{4}\sqrt{\frac{d^3}{GM}}$
- (C)  $\pi\sqrt{\frac{d^3}{3GM}}$
- (D)  $2\pi\sqrt{\frac{d^3}{GM}}$
- (E)  $\frac{\pi}{4}\sqrt{\frac{d^3}{GM}}$

23. A mass is attached to an ideal spring. At time  $t = 0$  the spring is at its natural length and the mass is given an initial velocity; the period of the ensuing (one-dimensional) simple harmonic motion is  $T$ . At what time is the power delivered to the mass by the spring first a maximum?

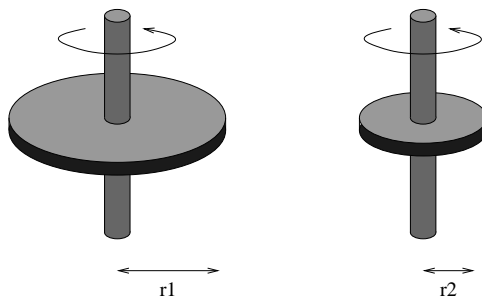
- (A)  $t = 0$
- (B)  $t = T/8$
- (C)  $t = T/4$
- (D)  $t = 3T/8$
- (E)  $t = T/2$



24. A uniform rectangular wood block of mass  $M$ , with length  $b$  and height  $a$ , rests on an incline as shown. The incline and the wood block have a coefficient of static friction,  $\mu_s$ . The incline is moved upwards from an angle of zero through an angle  $\theta$ . At some critical angle the block will either tip over or slip down the plane. Determine the relationship between  $a$ ,  $b$ , and  $\mu_s$  such that the block will tip over (and not slip) at the critical angle. The box is rectangular, and  $a \neq b$ .



- (A)  $\mu_s > a/b$   
 (B)  $\mu_s > 1 - a/b$   
 (C)  $\mu_s > b/a$   
 (D)  $\mu_s < a/b$   
 (E)  $\mu_s < b/a - 1$
25. Two discs are mounted on thin, lightweight rods oriented through their centers and normal to the discs. These axles are constrained to be vertical at all times, and the discs can pivot frictionlessly on the rods. The discs have identical thickness and are made of the same material, but have differing radii  $r_1$  and  $r_2$ . The discs are given angular velocities of magnitudes  $\omega_1$  and  $\omega_2$ , respectively, and brought into contact at their edges. After the discs interact via friction it is found that both discs come exactly to a halt. Which of the following must hold? Ignore effects associated with the vertical rods.



- (A)  $\omega_1^2 r_1 = \omega_2^2 r_2$   
 (B)  $\omega_1 r_1 = \omega_2 r_2$   
 (C)  $\omega_1 r_1^2 = \omega_2 r_2^2$   
 (D)  $\omega_1 r_1^3 = \omega_2 r_2^3$   
 (E)  $\omega_1 r_1^4 = \omega_2 r_2^4$